Ocean Sci. Discuss., 11, C426–C441, 2014
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Ocean Science
Discussions
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Interactive comment on "Is coccolithophore distribution in the Mediterranean Sea related to seawater carbonate chemistry?" *by* A. M. Oviedo et al.

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Received and published: 27 May 2014

We would like to thank the anonymous referee #1 for the comments on the manuscript. Please find our responses below:

1. General comments - A general description of the regional settings could be added, describing the seasonality, wind regime, main water masses, currents and river discharge regime of the Mediterranean Sea. Despite of the large-scale of this study and the fact that the samples appear to have been collected along the deeper part of the Mediterranean Sea, you are dealing with a relatively small and land-locked ocean basin with a complex coastline and topographic relief where the phytoplankton dynamics may

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Discussion Paper

be highly influenced by the presence of gradients along the coastal-neritic-oceanic transition (see Bakun and Agostini, 2001). This part could be added as part of the introduction or as a separate section called “Regional settings”. A figure nicely illustrating the main currents and water masses would also be welcome.

Response: A general description of the oceanographic settings will be added in a new section (Regional settings). Here, we will briefly describe the seasonality, main water masses and currents, general wind regime and wind induced upwellings. Seasonality will be addressed further in the discussion; which will emphasize the comparison of our results with results obtained during other seasons (i.e. Ignatiades et al., 2009 and Knappertsbusch, 1993). Please see the response to the specific comment referring to this issue.

- Even though there is no doubt that the Mediterranean Sea is, on average, an oligotrophic environment (and especially the eastern part), it would be interesting to investigate how much short-term variability there is. The authors should explicitly take into account that their observations represent a 23 days’ snap-shot of something that is expectedly highly variable in 3-D space as well as in time, and that short-term variability may well mask any relationship with long-term average oceanographic gradients. For this, contextualizing of the cruise in terms of seasonal and oceanographic characteristics of the Mediterranean Sea would be welcome. A short description of the meteorological and oceanographic conditions prevailing during the cruise could be provided in order to give a clearer picture on the environmental conditions at the time of the sampling, and to clearly demonstrate that conditions did not vary significantly in space and time. This is particularly important when dealing with seawater samples collected from areas influenced by land where environmental conditions may vary very quickly, with major consequences to the productivity, composition and distribution of phytoplankton. In case it is not possible to acquire such data, the authors should at least discuss these limitations of the study in the manuscript.

Response: A description of the meteorological conditions as well as a general de-

OSD
11, C426–C441, 2014

scription of the different surface water masses during the cruise will be given in a new section (Regional settings). Please note that the latter are published in other articles within this special issue or are in OSD (i.e. Hainbucher et al., 2013, Tanhua et al., 2013 and Álvarez et al., 2013).

- Since conditions may vary significantly in only 28 days, and given that the factor "light" was not considered in this study, I would be more cautious when inferring the relatively higher importance of seawater chemistry in coccolithophorid ecology in comparison to light and nutrients. In a recent regional study west off Portugal, light was observed being the triggering factor of a coccolithophore bloom within a few days, under eutrophic conditions near the coast (Guerreiro et al., 2013).

Response: We are conscious of the limitation of our approximation to understand coccolithophores distribution using field samples. It is virtually impossible to record all possible biotic and abiotic variables that can influence the distribution of phytoplankton. We have, certainly, sampled only part of them. As the reviewer highlights, light can be a limiting factor specially when nutrients are not limiting, and trigger a bloom within few days, as in the study by Guerreiro et al., (2013). Not only we did not measure light, but we sampled every station only once, thus we can not follow a response to variations in meteorological conditions. Most likely, such a response won't be immediate (specially because the variable that we recorded –cell densities- relates to cell division). Variations in light, however, are larger on the vertical profile and due to cloud coverage. We will address the relationship between coccolithophore abundances and depth and coccolithophore abundances and meteorological conditions at the time of sampling, as an indirect way to address possible changes in light. We will discuss the limitations of such approach.

-This study would benefit from a figure representing the variation of sunlight (cloud coverage) and chl-a concentration during the cruise, which could be achieved with data from satellite imagery. For example, building a west - east transect representing the daily averaged value of the two proxies vs. longitude. Such plot would provide a

OSD
11, C426–C441, 2014

more robust background for the period under study and at the same time, providing a more accurate term of comparison in terms of phytoplankton productivity between the two margins of the Mediterranean Sea during the cruise.

Response: The Figure suggested by the reviewer is presented (Figure 1). In this figure, gaps correspond to cloud covered observations and the temporal-spatial location of the samplings during our study is indicated by black dots. The transect is representative of 18Km in latitude, (two pixels at 9Km resolution).We propose a synoptic view of the variations in Chlo-a and cloud coverage by further averaging the days of April 2011 along the transept (Figure 2). The data in these Figures is derived from satellite observations (MedOC4, Volpe et al., 2007). From Figure 2 we can distinguish for the month of April 2011 a rather constant relation cloudy-sunny days in the western Mediterranean (about half of the observations were cloud covered) and a more variable eastern Mediterranean, with more than 60% cloud covered days in the eastern most part of the basin, a minimum in cloud coverage (40% of days) at about 25°E (south of Crete). This minimum corresponds to the only segment of the transect directly influence by northern wind regimes. After this point, values are around 50% as those on the western Mediterranean. According to the Meteorological reports during the M84/3, approximately 58% of the sampling days were cloudy at the time of reporting with a majority of sunny days from south Crete towards the Adriatic. This scenario is not so far from the satellite observations (it does not imply that the conditions during sampling were exactly the same, as the reports were done twice per day at fixed time). Therefore, along most of the transect the conditions were mainly steady (with variations of less than 10%) and the sampled days were representative, in terms of cloud coverage, of the conditions during April 2011.

2. Specific comments

Introduction

The introduction is very well written and the study certainly brings a very consider-

OSD

11, C426–C441, 2014

able input concerning the taxonomy and distribution of coccolithophores in the Mediterranean Sea, especially concerning its haploid stage life and relationship with seawater carbonate chemistry. But I would avoid generalizing too much 23 days of seawater sampling along 28 stations to an entire up-to-date state of the art for the coccolithophores from this region (page 616, paragraph 25), especially considering that the discussion does not take into account the short-term variability (in space and time) related to the meteorological and oceanographic dynamics of the Mediterranean Sea. For example, differences between the present study and those presented by Ignatiades et al. (2009) concerning the distribution of the main phytoplankton groups along the Mediterranean Sea for the month of June (1999) suggest the occurrence of interannual variability for phytoplankton, which is not possible to address with the present data-set.

Response: We will specify the limits of our contribution and findings in the introduction, as well as in the conclusion section. As mentioned before, seasonality will be addressed further in the discussion; which will emphasize the comparison of our results with results obtained during other seasons (e.g. Ignatiades et al., 2009 and Knappertsbusch, 1993). Concerning the distribution of the main phytoplankton groups along the Mediterranean Sea, there are no major differences with the trend observed by Ignatiades et al., (2009). When they wrote about dominance of the different phytoplankton groups, they referred to species richness. Ignatiades et al. results on cell densities show that coccolithophores dominated both, the eastern and western basins. Concerning the coccolithophore community, the study of Knappertsbusch (1993) suggest the occurrence of interannual variability. His sampling was divided in two periods: February-March (1988) and September-October (1986). Knappertsbusch observed higher cell densities during late winter. In this period, coccolithophore cell density increased towards the eastern Mediterranean, reaching 230000 cell/L in the Levantine basin. During September-October these pattern reversed. Our results resemble the pattern of those corresponding to September-October in Knappertsbusch work, although with higher cell densities. A decade after (1999), Ignatiades et al. (2009) observed in summer (June), the same pattern we have observed in Spring and Knap-

OSD
11, C426–C441, 2014

pertsbusch (1993) observed in late summer: increasing cell densities towards the western Mediterranean.

Material and Methods

- I would maybe divide section 2.1. “Hydrography and phytoplankton“ in two separated sections called “Sampling” and “Phytoplankton analysis”. Methods concerning the hydrography are actually described in section 2.2. Environmental parameters.

Response: We agree with the separation of section 2.1

- It is not completely clear if you are also referring to the counts when you refer that hetero- and holoccolithophores were treated separately. In case they were counted separately, please provide the minimum and maximum number of counts for each.

Response: This minimum and maximum numbers include the two life stages.

- It is not clear which samples are represented in Figure 2, although I assume that they concern the W-E transect along the Mediterranean Sea.

Response: Yes, represented samples are those mentioned in the W-E transept, which is described in Figure 1. We will make clearer this information in the Figure caption of all Figures concerning the W-E transept.

- The coordinates, date, depth and analyzed proxies of each station should be provided in a table.

Response: A table displaying the coordinates, date, and depth will be added. The proxies analyzed in each station and the respective data can be extracted from http://cdiac.ornl.gov/ftp/oceans/CLIVAR/Met_84_3_Med_Sea/.

Results

- Page 620, section 3.1: It would be interesting to take this great opportunity to explore in more detail the relationship between the main phytoplankton groups and the envi-

OSD

11, C426–C441, 2014

ronmental parameters during the sampling period, instead of only taking into account the larger-scale W-E physicochemical parameters and reporting to the full description of the settings presented by Tanhua et al. (2013b) and Álvarez et al. (2013).

Response: We will include the results of a correlation analysis between the other phytoplankton groups and discuss these results.

- Page 620, P.15: I think that this agreement between your in-situ measurements and the satellite data would be better demonstrated if you would use a map showing an averaged Chl-a concentration for each station, instead of generalizing 4 days of satellite data for the 23 days of the cruise. This way you would be providing information on the spatial and temporal variability of Chl-a production during the sampling period. It would also allow you to more accurately compare different sectors/basins within of the Mediterranean Sea, thereby providing a more robust basis from which you could compare your in-situ measurements.

Response: Please see the response to the last general comment. We will also refer to Chlo-a available data corresponding to the M84/3 cruise, published in the special issue (by Rahav et al. 2013).

- Page 620, P. 15-20: "coccolithophores were the most abundant group during the sampling, in all main Mediterranean basins (68-99%)". This remarkable result somewhat contradicts previous observations from Ignatiades et al. (2009) reporting the dominance of diatoms in the west and of dinoflagellates+coccolithophores in the east, during the month of June 1999. You should discuss this difference in the manuscript.

Response: In fact, there is no major difference with the trend observed by Ignatiades et al., (2009). When they wrote about dominance of the different phytoplankton groups, they seem to refer to species richness. In their words: "In terms of taxa relative abundance, dinoflagellates and coccolithophores dominated at the eastern stations and comprised, on an average, 43.29– 52.60% and 27.59 – 44.24%, respectively, of total population abundances, whereas diatoms dominated (36.94 – 52.70%) at the western

OSD
11, C426–C441, 2014

stations". However, their Figure 4 clearly presents the data on cell densities. In our introduction we have quoted Ignatiades et al. statements about the species abundance of each phytoplankton group due to its importance in describing the community structure (page 616 -10). However, given that only coccolithophores were identify to the species level, we will focus on the comparison with the respective results (on cell densities) in Ignatiades et al. (2009), where coccolithophores dominated both, the western and eastern basins.

- Page 621, P. 15: "Some of these species were negatively correlated to phosphate concentrations and only D. tubifera showed a high positive correlation with temperature". Please specify which species were negatively correlated with phosphate.

Response: It will be specified.

- D. tubifera is not correctly written.

Response: It will be corrected.

- Page 621-622: The spatial and vertical distribution of the species within Group 1 and Group 3 are mentioned in the text, but not Group 2.

Response: It is mainly described in the last part of the discussion. It will be specified in this paragraph.

- Page 621, P.25: Labels for the main basins should be given in Figure 1.

Response: These labels will be added.

- The section "Results" is focused and well written but I have the general feeling that it may be perhaps too much "succinct" and therefore could be extended and more detailed. For instance, you don't characterize the meteorological conditions during the cruise and you almost don't refer the relation between the species and the environmental parameters (their geographic and vertical variation).

Response: The Meteorological conditions will be described in a new section on Re-

OSD
11, C426–C441, 2014

gional settings. We have described the species distribution along the transept for the species that clustered together. These were among the most abundant and displaying clearer distribution patterns (page 621-622 and Table 3). The relationship between single species and environmental parameters is also given just for these species (Spearman's correlation, Table 3). For the coccolithophore community in general, it is given by the results of the BIOENV routine that relates the differences or similitudes in the phytoplankton community among the different stations, with the differences or similitudes in environmental parameters among stations (Tables 1 and 2). Coccolithophore species that did not cluster showed a patchy distribution and/or were infrequent. There are details in the geographic variation of species distribution that were not discussed. For instance, the different community composition in the center of the Tyrrhenian basin, or the differences in the distribution of the two life stages (holo- and hetero-coccolithophores) of a single species. We will describe these issues in the Results section and discuss its implications.

Discussion

Main phytoplankton community - Page 623, P. 5: the names of the basins and seas should be indicated in Figure 1.

Response: These names will be added.

- "This study documents the dominance of coccolithophores in the phytoplankton community (Fig. 3), including the ultra-oligotrophic eastern region where nutrients concentrations fell below detection limits". . . for the period under study.

Response: The sentence will be modified accordingly.

- Page 623, P. 10-15: "Even though only reached at the Gibraltar Strait, the highest cell density of coccolithophores was 1–2 orders of magnitude higher than for the other phytoplankton groups." This sentence is not completely clear to me. . . Response: We propose the following re-ordering of the sentence: "At the Gibraltar strait, where

OSD
11, C426–C441, 2014

all phytoplankton groups showed the highest cell densities, coccolithophore cell density was between 1 – 2 orders of magnitude higher than for the other phytoplankton groups"

- Page 624, P. 1: "However, a threshold in nutrient concentrations, below which coccolithophores would perform better than other groups in a competitive scenario; would affect their populations". You mean that under oligotrophic conditions, coccolithophores are in advantage to compete for the available nutrients in comparison to the others phytoplankton groups?

Response: Our sentence was connecting to the next, regarding the possible phosphorus limitation for phytoplankton other than coccolithophores. In this sense, yes, we meant that under oligotrophic conditions, coccolithophores could be in advantage to compete for the available phosphate in comparison to the others phytoplankton groups. We will omit the first sentence.

- Page 624, P.10: "We suggest that the relative success of coccolithophores over diatoms, dinoflagellates and silicoflagellates during April 2011 in all Mediterranean Sea basins, can be due to a combination of environmental parameters rather than nutrients and turbulence alone." But in the following chapters you mostly discuss the influence of seawater chemistry in the distribution/diversity of coccolithophores, but not as being the cause of the remarkable dominance of coccolithophores over diatoms and dinoflagellates.

Response: One limitation to evaluate whether carbonate chemistry parameters were related to the dominance of coccolithophores over diatoms or dinoflagellates is that all stations were dominated by the former group and all groups showed higher abundances in the western basin. Thus, making it difficult to clearly separate a preferred set of environmental conditions for each phytoplankton group. While coccolithophores are thought to be harmed by low CO32- concentrations, diatoms might increase its biomass faster at higher CO2 concentrations. This study, however, does not provide evidence to suggest that the relative higher CO32- concentration in the Mediterranean

OSD
11, C426–C441, 2014

Sea caused coccolithophores to dominate over diatoms. First, we did not sample in other seas with higher CO2 – low CO32-; second, an experimental set up would be necessary to disentangle the cause(s) of coccolithophores dominating diatoms at the conditions of our sampling. We suggest that the relative success of coccolithophores over diatoms, dinoflagellates and silicoflagellates in all Mediterranean Sea basins, can be due to a parameter(s) not measure during this study or to a threshold in a resource that limits the growth of the other phytoplankton groups, but that covers the requirements of coccolithophores. As mentioned before, we will include the results of the correlation analyses between diatoms and selected environmental variables. We will re-write the paragraph 10 in page 624 and omit the last sentence, which might suggest that carbonate system parameters could explain coccolithophores dominance.

Heterococcolithophoes and holococcolithophores - This section is perhaps too long and dealing with too many different and complex aspects. It could be re-organized in separated sections, such as: 4.2. Heterococcolithophores: species assemblages and relationship with the environmental settings 4.3. Heterococcolithophores versus holococcolithophores.

Response: The section will be divided in two sections

- Page 624, P.25: “it is therefore plausible that the availability of the necessary resources of carrying out calcification should facilitate coccolithophore’s growth in the ocean”. Which resources are those? Please be more specific.

Response: We meant those resources concerning the carbonate system. It will be specified: “it is therefore plausible that the availability of the necessary resources of carrying out calcification (i.e. CO32-, HCO3-) would facilitate coccolithophore’s growth in the ocean”

- Page 626, P.25: “Overall, we suggest CO32- and pH as functionally related important variables in explaining heterococcolithophore distribution in the Mediterranean Sea.” It remains unclear the reason behind the remarkable dominance of coccolithophores

OSD
11, C426–C441, 2014

over diatoms and dinoflagellates, especially in the western nutrient-richer part of the Mediterranean Sea. Is it because the Mediterranean Sea is generally enriched with CO32- in comparison with other marine environments?

Response: As for the comment in Page 624, P.10; this study does not provide evidence to suggest that the relative higher CO32- concentration in the Mediterranean Sea caused coccolithophores to dominate over diatoms. First, we did not sample in other seas with higher CO2 – low CO32-; second, an experimental set up would be necessary to disentangle the cause(s) of coccolithophores dominating diatoms at the conditions of our sampling. We suggest that the relative success of coccolithophores over diatoms, dinoflagellates and silicoflagellates in all Mediterranean Sea basins, can be due to a parameter(s) not measure during this study or to a threshold concentration in a resource that limits the growth of the other phytoplankton groups, but that covers the requirements of coccolithophores. As the reviewer says, the reason behind the dominance of coccolithophores over diatoms and dinoflagellates remains unclear.

Conclusions - This part could be slightly extended, while succinctly referring in what manner was the seawater chemistry important in the distribution of heterococcolithophores, and what were the distinct environmental parameters influencing the distribution of the two life stages. It could also be mentioned the remarkable dominance of coccolithophores over diatoms and dinoflagellates.

Response: It will be extended by adding the precise information.

Figures Figure 1 – The Chl-a image represents an averaged Chl-a concentration at the sea surface for the days 27, 18, 14 and 8 of April? As mentioned above, you should clearly demonstrate that conditions did not vary significantly during the cruise before generalizing 4 days of Chl-a data for a period of 23 days covering the entire length of the Mediterranean Sea. The map is lacking labels indicating the names of the main basins and seas.

Response: Figure 1 shows the Chlo-a concentration for each of those days. Each of

OSD
11, C426–C441, 2014

the four images cover the area that was being sampled on the few days before and after. The Figure will be edited accordingly and we will describe the meteorological conditions during the sampling events.

Figure 7 – It is interesting to note that the deeper species do not present a clear W-E gradient as in the case of the other two heterococcolithophore groups. You think it is because they are relatively more dependent of nutrients' availability than of seawater carbonate chemistry?

Response: It is true that we did not observed a strong association with seawater carbonate chemistry, as we did for nitrate+nitrite; even further, these species have been previously associated with the nutricline (Molfino and McIntyre, 1990; Triantaphyllou et al., 2004). During our sampling, phosphate was depleted in the eastern basin and we still found these species to be present, while nitrate+nitrite were available in both basins. Thus, it is likely the case that their stronger"dependence" on nitrate+nitrite than on other resources available in a W-E gradient, including seawater carbonate system variables, explain its presence along the Mediterranean Sea, showing no clear W-E pattern.

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Interactive comment on Ocean Sci. Discuss., 11, 613, 2014.

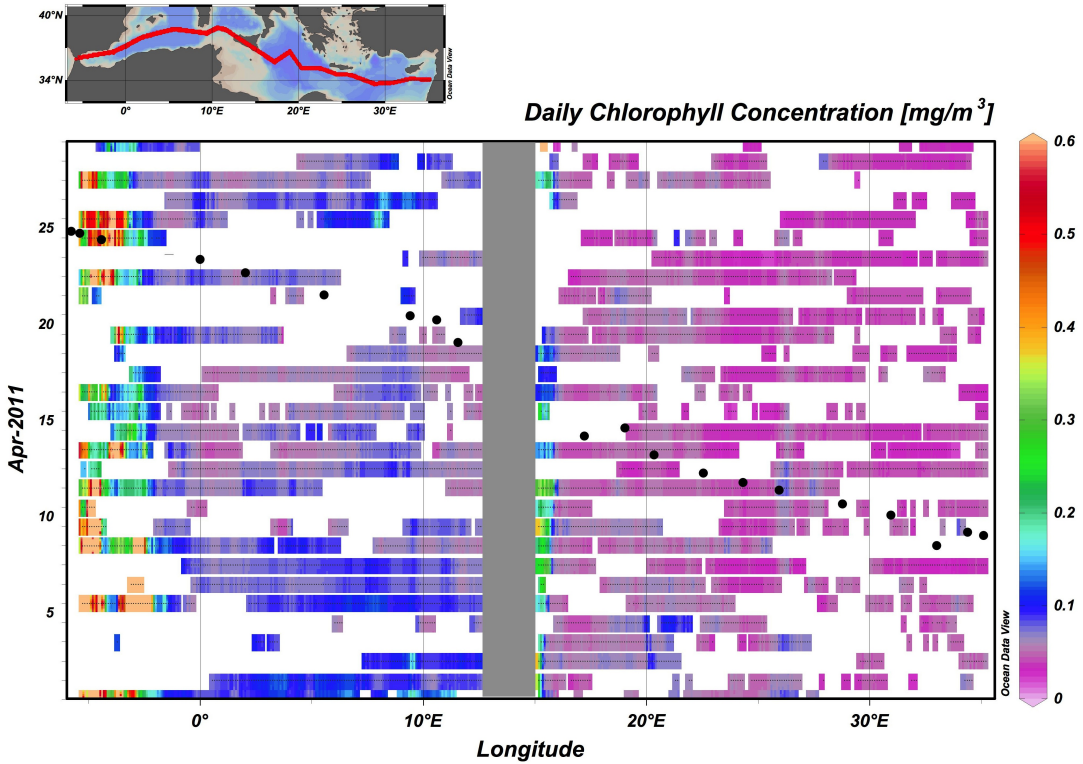

Fig. 1. Figure 1. Daily mean of Chlorophyll-a concentration from satellite data (MedOC4, Volpe et al., 2007) along the transept of the M84/3 are plotted for the month of April.

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Discussion Paper

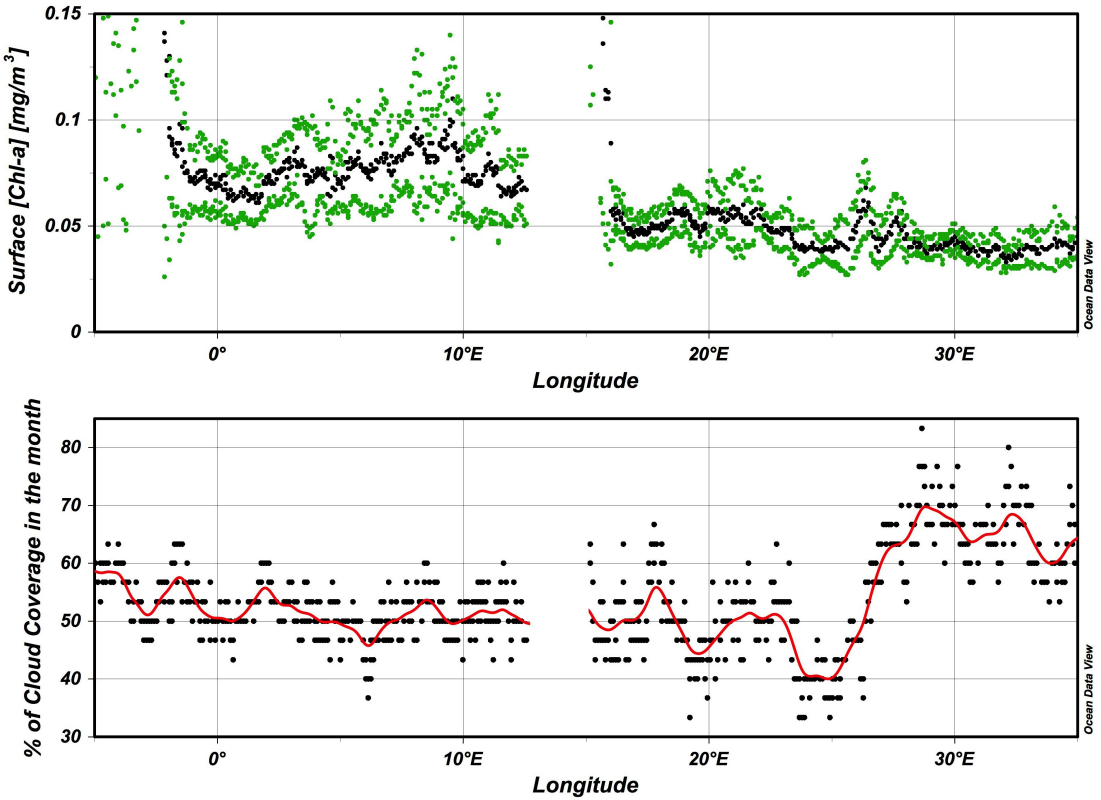

Fig. 2. Figure 2. April Chlorophyll-a concentration along the M84/3 transept. Mean (black dots) and SD (green dots). Below: Mean (red line) and actual values (black dots) of April cloud coverage percentage.

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